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A SURVEY OF THE
INSTRUMENT LANDING SYSTEM
GLIDE PATH

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B. J. Lauff

A SURVEY OF THE INSTRUMENT LANDING SYSTEM GLIDE PATH

by

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PREFACE

The investigation of the operating characteristics of the glide path equipment of the Instrument Landing System was made in the eleven week period which comprises the Winter Term of the third year in the Electronics Engineering course of instruction at the U. S. Naval Postgraduate School at Annapolis, Maryland. The field work was done at the Federal Telecommunication Laboratory at the Westchester County Airport, White Plains, New York. There the author assisted Mr. Sidney Pickles in a series of air and ground tests on a glide path installation. The tests covered the period from January 3, 1949 to March 18, 1949.

The tests were made in an attempt to complete the theory of operation of a piece of equipment which has been in actual operation in all parts of the world for several years. The difficulty of making measurements on the glide path (the useful glide path lies almost entirely at distances above the ground which cannot be probed from the ground) and the inadequate equipments and techniques for making measurements at the glide path frequency has left several factors uninvestigated and the inter-relation of many factors open to considerable question. While Mr. Pickles and the author feel that their work has added to the knowledge of the theory of operation of the equipment they are convinced that the theory is still inadequate to explain some of the phenomena observed during the test period.

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CHAPTER I

THE EQUI-SIGNAL GLIDE PATH

The equisignal glide path system has been in constant use since before the War. While the equipment has been continually improved and many studies of its operation have been made, considerable difficulty is still experienced in many installations in obtaining a glide path having the desired angle and stability.

In recent investigations conducted at the Westchester County Airport by Mr. Sidney Pickles, the effects of relative phase of the signals in the upper and lower antennas and of cross modulation products in the two antennas upon the glide path angles, clearances, range, and path sharpness were studied. A method of determining the effective reflecting plane for any glide path installation was devised. Most of these factors have long been recognized but their significance has not been properly evaluated.

The following excerpts are quoted since they give an excellent explanation of the theory upon which the system is based and indicate the factors which have been considered in adjustment of the glide path equipment.

> The equisignal type of glide path is produced by overlapping radio frequency patterns, each pattern being modulated by different audio frequencies. The receiver used in the aircraft is then equipped with suitable audio filters which respond to the respective audio modulations in the radio frequency patterns. The course or path is defined as the region in which equal audio signals are produced in the receiver. With this type of glide path, the glide angle is held constant as far from the transmitting antennas as a usable signal for actuating the receiver can be received.

The overlapping radio frequency patterns mentioned above are obtained by placing two horizontally polarized antennas one above the other at considerably different distances above the ground. The lobes in the vertical radiation pattern of the upper antenna may make several intersections with the fewer number of lobes in the vertical radiation pattern of the lower antenna. The number of intersections will depend upon the relative amplitudes of the signals driving thetwo antennas as well as the ratio of their heights above ground. Figure (1) shows part of the vertical radiation patterns of two vertically spaced antennas. From this figure it can be seen that if the radio frequency energy driving one antenna is modulated with an audio frequency and the energy driving the other antenna is modulated with another audio frequency a glide path can be produced at an angle "a" with respect to the ground. The glide path is by definition the locus of points of equal radiation intensities of the first lobes of the upper and lower antennas assuming equal percentages of modulation.

The glide path equipment under discussion generates a radio frequency of 330 megacycles which is divided to drive both the upper and lower antenna. The radio frequency energy radiated by the lower antenna is modulated by 90 cycles and the energy radiated by the upper antenna is modulated by 150 cycles.

The patterns in Figure (1) demonstrate that the amplitude ratios of the two signals are a considerable factor in

determining the glide path angle which will be produced by a given antenna array. It is seen that if the amplitude of the upper antenna signal is increased appreciably, the glide path angle is increased a small amount and also that false courses occur at angles of a_1, a_2, a_3, a_4, a_5, and a_6. Under these conditions a number of courses would be produced and considerable confusion would result. Therefore, such amplitude relations between upper and lower antenna radiations are to be avoided.

If the amplitude of the radiation of the upper antenna were to be appreciably decreased from that shown by the solid line on Figure (1) the first intersection of the upper and lower antenna lobes would be somewhat indefinite. This is due to the fact that the intersection occurs below the peak of the lobe of the upper antenna. At angles lower than a both signals decrease and at angles above a both signals increase. Glide path "a " would not only be very "dull" but would vary drastically with minor changes in relative amplitudes of the two radiated carriers.

The amplitude ratios shown by the solid lines in Figure (1) produce a first false path at a vertical angle a' considerably greater than the angle "a". While the original specifications demanded that the first false path angle be not less than six times the desired path angle it has been found in practice that if the first false path produces a glide angle three times the desired glide angle no confusion results as to which is the correct path.

The optimum ratios between the radiation amplitudes and between the heights of the two antennas was determined as a compromise between:

a. Sharpness of on-course signal

b. Nearly equal minimum clearances (both below and above path)

c. Prevention of a false path at an angle less than six times the desired glide path angle (required by specification)

(These factors will each be discussed in detail in later chapters).

In order to determine this information statistically, several antenna height ratios and radiation amplitude ratios were selected. Plots of the vertical radiation patterns of the upper and lower antennas were then made in a manner similar to that shown in Figure (2) which is a rectangular plot of Figure (1). These curves were calculated from Equation 3 of Figure (3). Since the horizontal directivity of the antennas is not a factor in this case, the expression $R'(\theta)$ can be considered unity. A tabulation of sharpness and clearances obtained from these curves is shown on following page.

Ratio of antenna heights	Ratio of amplitudes	Maximum Clearance Below Path Db	Maximum Clearance Below Path Vertical angle expressed as ratio to G.P. angle	Minimum Clearance Above Path Db	Minimum Clearance Above Path Vertical angle expressed as ratio to G.P. angle	Relative Sharpness on 2.5° path	First False Path
5.21	.550	6.40	.600	3.12	2.12	27.1	15.4°
4.75	.462	4.60	.600	5.0	2.14	19.1	16.5°
4.25	.444	4.08	.600	6.12	2.40	14.1	17.8°

From this tabulation it is seen that for height ratios other than 4.75 and amplitude ratios other than .462 clearances above and below path become quite unequal. Since these ratios also meet the false path requirement they were chosen in full appreciation of the compromise in path sharpness that they represent.

These clearance and sharpness characteristics can be maintained while varying the glide path angle merely by raising and lowering the upper and lower antennas in such a way as to maintain the specified ratios. In the glide path under description, glide path angles between 2° and 5° are obtainable in $\frac{1}{4}$ degree steps up to 4° and then by $\frac{1}{2}$ degree steps up to 5° in which all clearance characteristics remain the same except for clearances between the fourth lobe of the upper antenna and the first lobe of the lower antenna. The upper antenna has sufficient inherent vertical directivity to decrease radiation at angles above approximately 15° by a small amount. Therefore, clearances between the fourth lobe of the upper antenna and the first lobe of the lower antenna are somewhat greater than shown in Figure (2) for glide path angles greater than three degrees.

If the antennas used for the production of the glide path have identical horizontal radiation patterns, the points of intersection of the first lobes of the upper and lower antennas will be at the same angle above the ground throughout the 360 degrees around the glide path equipment. Such an intersection of patterns is seen to be contained in the

surface of a cone as shown in Figure (4).

Since the equipment must not constitute a hazard it is displaced three hundred to five hundred feet to the side of the runway. The intersection of the cone and a vertical plane in the centerline of the runway is hyperbolic and does not touch the runway. Operationally, a straight line glide path with a flare out near the point of contact is desired. The modifications made in the horizontal patterns of the two antennas to accomplish this need not concern us in our present considerations.

CHAPTER II

CONSIDERATIONS WHICH DETERMINED THE ORIGINAL SPECIFICATIONS

The planners who set out the original specifications for the operation of the glide path equipment desired that the glide path should offer a helping hand to a pilot attempting a landing under conditions of extremely poor visibility. They desired the pilot be guided to the approach lane by a localizer equipment, that he hold a constant altimeter setting down the approach lane until he intercepted the glide path, and that he then follow the glide path down to contact with the runway.

The description of the formation of the glide path by means of overlapping patterns (Figure 1) revealed the possibility, under improper adjustment of the equipment, of the coexistance of several courses at nearly the same glide angle. Even under conditions of proper adjustment of the relative amplitudes of the two radiations a false path can exist very near to the desired glide path if the first lobe of the lower antenna contains only two lobes of the upper antenna. To the pilot who is relying on the glide path for guidance the possibility that he might be flying a false, unmonitored, path without any indication that it is not the proper path is a distinct disadvantage of the equipment. Since the proposed method of producting the glide path did not allow the complete elimination of false paths a compromise requirement of no false path at less than six times the desired glide path angle was written into the original specifications. It was felt

that a pilot finding himself on this false path would soon realize from the steep angle of descent that he was not on the proper path. Actual operation with the equipment has since shown that the first false path identifies itself with reversed corrective signals, i.e. the indicating equipment gives a "fly up" signal for positions above the path and a "fly down" for positions below the path. A pilot attempting to fly the first false path finds himself directed to either the second false path or the desired path. Had this fact been recognized from consideration of the phase of the signals in Figure (1) the design of the antenna array could have been simplified by the requirement that the <u>second</u> false path should be at an angle greater than six times the glide angle.

The desire that the aircraft be kept reasonably close to the designed glide path at all times during its descent led to the sharpness specification. A broad path, i.e. one in which the angle of intersection of the first lobes of the upper and lower antenna was large, would allow the aircraft wide excursions from the glide path before significant off-path indications were received. The correction then made to remedy this situation would not make itself felt to any significant extent to the offpath indicator until the aircraft had crossed the path and occupied a position in error in the opposite direction. The aircraft would follow a damped sinusoidal path in its descent. A sharp path, on the other hand, provides excellent guidance in the early stages of

approach since the error signal per degree off path is much greater than that of the broad path. This advantage rapidly becomes a disadvantage as the runway is approached. At this close range an altitude displacement of a few feet represents a considerable angular displacement. In attempting to follow the rapid and violent alternations of the "up-down" indicator the pilot may place his aircraft in an unfavorable landing attitude or overshoot his landing and loose the path completely. The sharpness originally specified was a compromise between these two conditions.

Experience in flying the glide path soon showed that even this compromise path tended to be too sharp for any but pilots experienced in its use. As the aircraft approached the glide path transmitter the inverse square of the distance law of radiation became effective in greatly increasing the number of volts per degree off path. The up-down indicator responds to the difference in the detected voltages of the 90 and 150 cycle modulations. As the equipment is approached the difference in detected voltages will increase while the ratio of modulated signals is held constant. (a constant ratio of modulated signals indicates a constant path angle on a straight line glide path). To the pilot it appears that he is flying farther and farther off path and his maneauvers to correct this usually results in his assuming a position in error in the opposite direction. An automatic gain control was designed for the glide path receiver which then received a constant number of volts per degree off path from a point

on the glide path several thousand feet from the equipment down to the point of contact.

The third specification which was determinantal in the design of the glide path antenna system was the requirement of nearly equal maximum clearance below path and minimum clearance above path. The definition of clearance as herein used can best be given with the aid of Figures (2 and 5). Figure (5) is a schematic representation of the method of making flight tests on the glide path radiation field. It depicts an elevation view of an aircraft amking a constant altitude flight through the radiation field along the extended centerline of the runway. The aircraft is equipped with an Esterline Angus recorder replacing the up-down indicator. Since the recorder is capable of recording voltages more than twice those which would give off-scale indications on the indicator this arrangement makes possible a much more thorough investigation of the radiation field. It can be seen that at several points along the flight course the intensity of radiation of the upper antenna approaches in magnitude the intensity of the radiation of the lower antenna. These points are called "low clearance" points. If the difference of detected signal voltages at one of these points is less than that necessary for full scale indication on the up-down indicator a pilot attempting to find the glide path will be led to believe that he is approaching the path but will find that the "path" vanishes as he continues on into it.

One means of overcoming the confusion of alternate full scale up and full scale down indications is to allow the indicator to respond to a wider range of voltage difference before full scale indication is reached. The limits of the broadening of this indication are; the maximum clearance below path shall give greater than full scale deflection, and the minimum low clearance above path shall not be less than full scale deflection. The specification of nearly equal clearances above and below path was considered to meet these requirements.

CHAPTER III

PHASE AND MODULATION EFFECTS WHICH INFLUENCE THE RADIATED FIELDS

The analysis which led to the acceptance of certain height and amplitude ratios for the glide path radiation system was based upon a consideration of the radiation fields as expressed in the simple radiation field equation and shown graphically in Figure (2). There are several factors which combine to alter both the signal received by the aircraft and the voltage difference which actuates the indicating equipment in the aircraft from that which would be expected in the ideal case.

1. Phase Shift Along the Glide Path

Due to the wide separation in electrical degrees between the upper and lower antennas of the glide path system the usual assumption of parallel lines of radiation is not valid for points nearer than about one mile. For these points the distance from the antennas must be considered as well as the heights of the antennas and the vertical angle of the reference point. Figure (9) shows schematically the distances which the various radiations coming from the glide path antennas and their images must traverse in going to some receiving point "P". This receiving point, when viewed from the glide path equipment, is considered to subtend a vertical angle approximately the same as the glide path angle in question. Equations (1) and (2), Figure (9), express the complete signals from the upper and lower antennas which arrive at the

point "P". By means of trigonometric and algebraic transformations of these equations, Equation (5) can be obtained. Equation (5) shows that the carriers emitted by the upper and lower antennas shift phase with respect to each other as the equipment is approached directly. This phase shift varies as the square of the height of the antennas and inversely as the distance from them. From this equation it is clear that such a phase shift between carriers is greatly increased as the glide path angle is lowered, which also means that the effect of the phase shift extends considerably further from the radiation system. As an example, for a two and one half degree glide path, Equations (6), and (7) have been included showing that a 70° phase shift occurs at a distance of 400 feet from the glide path antennas. Figure (10) is plotted from an extension of Equation (5) which predicts the phase shift down the center line of the approach path.

2. Phase of Antenna Lobes

An investigation of the radiation patterns shown on Figure (2) indicates that alternate lobes of the radiation from the upper antenna re of opposite phase. From general considerations it would seem necessary that the phase of the carrier radiated from the upper antenna should be adjusted so that the first lobe of the upper antenna is in phase with the carrier in the first lobe of the lower antenna. Under these circumstances the second lobe of the upper antenna would have a carrier phase opposite to that of the carrier

phase in the first lobe of the lower antenna. The third lobe of the upper antenna would be in phase with the first lobe and the fourth would be in phase with the second.

3. Distortion in a Linear Detector due to Carrier Phase Shift

If two carriers of the same frequency and amplitude and modulated equally with different audio frequencies are detected with a linear detector the resultant output is a function of the relative phases of the carriers. When the carriers are considerably out of phase the detection process results in the production of harmonics of the modulating frequencies and cross modulation frequencies. (Pickles, 4). The effects of phase shifts between two modulated carriers of equal amplitude on the detected signal is shown in Figure (11). From the curves of this figure it is apparent that considerable latitude is allowable in phasing the carriers for detection. Phase shifts of plus or minus 30 degrees between carriers produce practically no change in the amplitude of the modulation frequencies and also no appreciable amount of harmonic frequencies or cross modulation frequencies are produced. Starting at about a 30 degree phase shift and continuing on to 180 degree phase it is seen that the energy of the modulation frequencies continually decreases, being converted mostly into cross modulation and harmonic energies.

4. Swamping Action in a Detector

A similar investigation of detector action on signals of unequal amplitudes shows that for certain phase condi-

tions the dominant signal tends to mask the other. Swamping action becomes effective only when the two signals are considerably out of phase (125 to 145 degrees) and is especially noticable when the ratio of amplitudes is small. A most interesting case is shown in Figure (12) where the ratio of the in phase amplitudes is 1.75.

5. Scalloping due to Cross Modulation in Transmitter

Since the relative phases of the two radiated carriers is so critical a means must be provided for maintaining their relative phases constant. The method employed in the glide path equipment is to obtain the two carriers by dividing the output of a single transmitter. The two carriers are then modulated with their respective audio frequencies and fed to the two antennas. The modulation is accomplished with a mechanical modulator. It is impossible in the present transmitting equipment to completely balance out the cross modulation through the dividing network. The signal radiated from each antenna contains, therefore, not only its characteristic modulation sidebands but also weak sidebands of the modulation frequency of the other antenna.

The radiation characteristics of the antennas will now be modified from that shown in Figure (2) by the vector addition of the modulation frequencies from the two antennas. The variety of ways in which these signals may combine is shown in Figures (6, 7, and 8).

CHAPTER IV

ADJUSTMENT OF THE EQUIPMENT AND RECOMMENDED MODIFICATIONS

The phase and modulation effects discussed in the previous chapter have considerable bearing on the proper adjustment of the upper and lower antenna phases for optimum glide path formation. Recognizing that the glide path lies wholly within the first radiation lobes of the upper and lower antennas, and that an out of phase condition of the two carriers at the point of detection gives rise to distortion and reduction of the audio frequency modulations it would seem desirable that the phase of the carrier radiated from the upper antenna should be adjusted so that the first lobe of the upper antenna is in phase with the carrier in the first lobe from the lower antenna. This is, also, the condition of maximum range of the glide path signal.

This adjustment of the radiated carriers in the first lobes places the carriers in the second and fourth lobes of the upper antenna opposite in phase to that of the carrier in the first lobe of the lower antenna. These two lobes, at their maximum amplitudes, give rise to the first and third low clearance regions. It is desired that the detected amplitude ratios in these regions be at least greater than that necessary for full scale deflection of the up-down indicator. It was noted in the discussion of swamping action phenomena that a phase difference of 140° gave a tremendous increase in the apparent detected amplitude ratio.

This condition can be achieved by phasing the radiations of the upper and lower antennas in their first lobes either plus or minus 40° with respect to each other. Either phasing adjustment would result in only a slight loss in range and the introduction of a negligible amount of distortion (reference Figure (11)).

The apparently alternative antenna phasing condition is resolved by the restrictions placed on the antenna system by the proximity phase effect (Figure (10)). In the discussion of proximity effect it was shown that, due to the wide aperture of the antenna system (six to eight wavelengths separating upper and lower antennas), the phase of the carriers from the upper and lower antennas of the glide path array shifted as the equipment was approached from a great distance. The shift consisted of a retard in the phase of the carrier radiated by the upper antenna. It was shown that for a two and one half degree glide path angle the phase of the two carriers shifted nearly 70° during the approach from a point several miles out to the point of contact with the runway. Since it would be most undesirable for aircraft using the signals near the landing area to find carriers of "on path" signals far out of phase it is preferable that the phase of the upper antenna signal, when far from the equipment, be advanced by approximately 40 degrees with respect to the phase of the carrier from the lower antenna. This advance would allow the carriers to come nearly into phase in the landing region and would provide the increased clear-

ances for the first and third low clearance regions above the path when considerably distant from the transmitting antennas.

The possibility of existance of cross modulation effects was noted in the previous chapter and the influence of cross modulation on the relative radiation intensity patterns is depicted in Figures (7, and 8). Suppose that some of the 90 cycle sideband signal is fed into the upper antenna. In this case the upper antenna will radiate two signals, the larger one being the standard 150 cycle modulation and the one of lower magnitude being of 90 cycle modulation. If the phase of this 90 cycle sideband radiation is opposite to the phase of the same sideband radiation coming from the lower antenna, the shape of the resultant lobe of 90 cycle modulation will be one in which the small signal from the upper antenna subtracts from the under side of the first lobe of the lower antenna. If the opposite is true, the small magnitude of 90 cycle sideband signal in the upper antenna will add to the first lobe of the lower antenna signal. Likewise, it is possible for 150 cycle sideband signal to be present in the lower antenna. In the event that this signal is radiated in phase with the first lobe of the upper antenna signal, it will be out of phase with the second lobe and in phase with the third and out of phase with the fourth. If the phase relations of the sideband signals are opposite to those described the magnitude of the first lobe of the upper antenna signal will be

less than required, the second will be greater, the third will be less and the fourth will be greater than that for which the equipment was designed.

Figure (7) shows a condition in which approximately 8% of each type of modulation was fed into the opposite antennas. It is to be noticed that the clearance below path under these circumstances is greater than normal. The path angle is raised and the first low clearance below the path is greater than normal. The clearance at the second low clearance region is decreased and the clearance at the third low clearance region is increased from normal. A consideration of the recording above this graph, taken on equipment with approximately 8% of cross feed, whows that the clearance below path was unusually high. The glide path antennas had been set for a two and one-half degree glide path angle and the equipment was located on a downhill slope which should have lowered the path angle. However, it is to be noticed that in this case the glide path angle was found to be two and six tenths degrees. The low clearance regions above the path are also seen to be unusually good.

On Figure (8) the opposite condition is shown. This is the condition in which the 90 cycle sideband signal from the lower antenna is in phase with the 90 cycle sideband signal from the upper antenna and the 150 cycle sideband signal from the two antennas is out of phase. The calculated clearance below the path is seen to be considerably less than in the previous case. The path angle is reduced very appreciably

and the first clearance above the path is decreased below normal. The recording confirms the calculations. The phase relations of radiated signals during this recording are 180 degrees from those in the previous recording.

It is to be noted that these cross feed effects do not have to be present in both antennas at the same time. That is, the cross feed of only one sideband signal can produce nearly the same effects. These results suggest the advisability of making such tests with glide path equipments in order to make optimum use of cross modulation or cross feed in the event that a small amount of it exists. If such investigation is not made, it is possible that the more undesirable condition may prevail in which case it will be difficult to obtain proper "up" signal below path and proper clearances above the path. This fact is in addition to phase effects on clearances mentioned previously. (Pickles, 5).

It was shown in Chapter I that the desire for equal clearances above and below path was one of the main considerations in the compromise that established the accepted height and amplitude ratios. The preceding portions of this chapter show that the original design calculations based solely on height and amplitude ratios, are valid only in the region of the first lobes of the upper and lower antennas, and then only in disregard of the cross modulation effects on the radiation intensity pattern. In the region of the second, third, and fourth lobes of the upper antenna where

carrier phase and cross modulation effects are significant the simple height and amplitude ratio diagram indicates, at best, only the general shape of the radiation field.

It was also shown that the first false path produced by the accepted height and amplitude ratios did not constitute a "false path" within the intent of the original specifications since it is impossible for a pilot, mistakenly or intentionally, to fly that path. It is the second false path in the radiation pattern which presents a dangerous indication since its character is identical to the desired glide path.

It may be determined by both flight and ground checks that the indicating equipment in the aircraft is capable of monitoring the radiation field over a one and one half defree region about the glide path (under present adjustments of transmitter modulation percentage and receiver sensitivity). The limits of this monitoring of field strength are the full scale "up" and full scale "down" on the indicator. Figure 10, which is a plot of the ratio of 90 cycle signal to 150 cycle signal, indicates the amount of "fly up" and "fly down" indication received at positions near the glide path. Flight recordings in general verify this plot. Figure (13) shows that the pilot is given a strong indication of his position for the same amount of error below path. If the radiation field around the glide path is allowed to be dissymetrical the dissymetry should be such as to give the pilot strong warning that his position is below the path and a lesser

indication for errors above the path where the danger is less.

In view of the above arguments it is recommended that the specifications of the system be modified and the antenna height and amplitude ratios be recalculated to produce a field in the region of plus or minus .75 degrees about the glide path that is as nearly symetrical as is possible under a modified specification of adequate low clearances above the path and a modified specification that no path indistinguishable from the desired glide path shall have a vertical angle of less than fifteen degrees above the ground.

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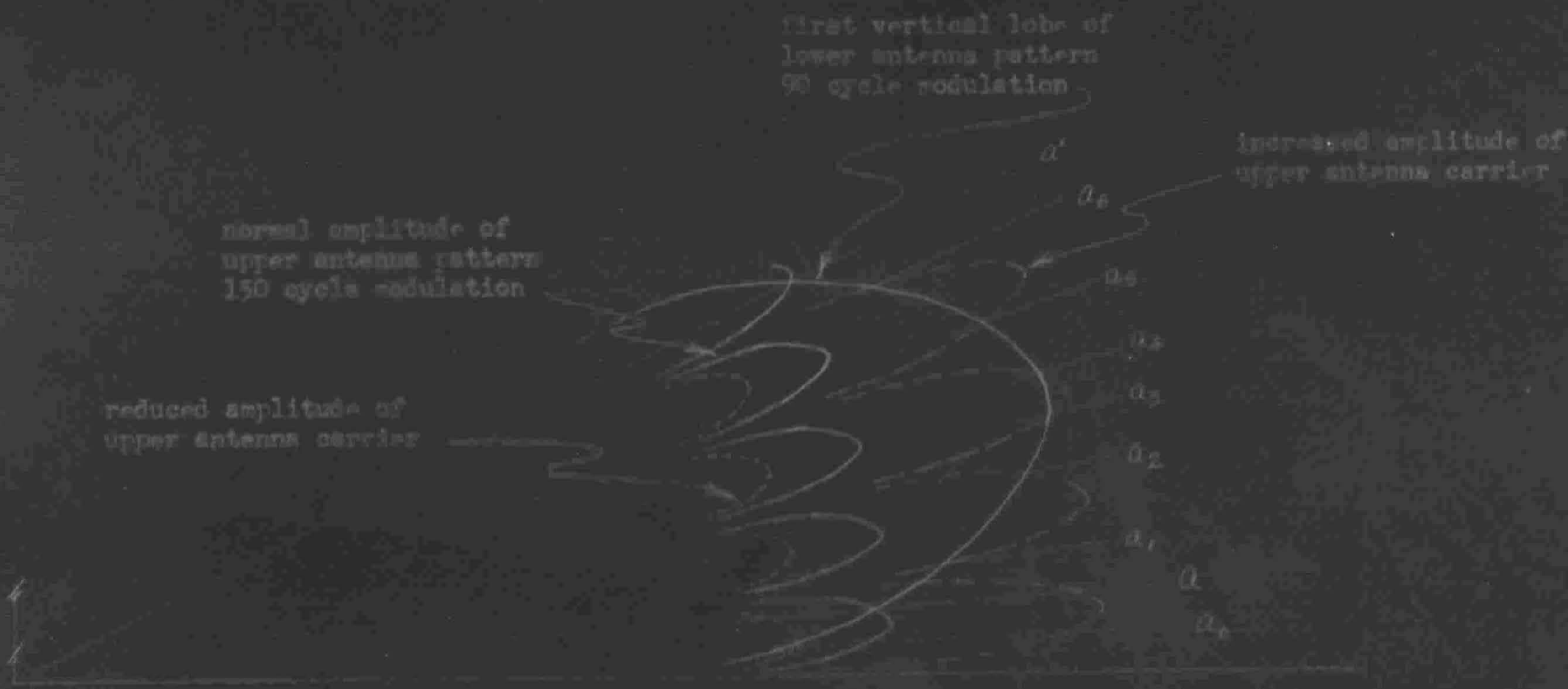
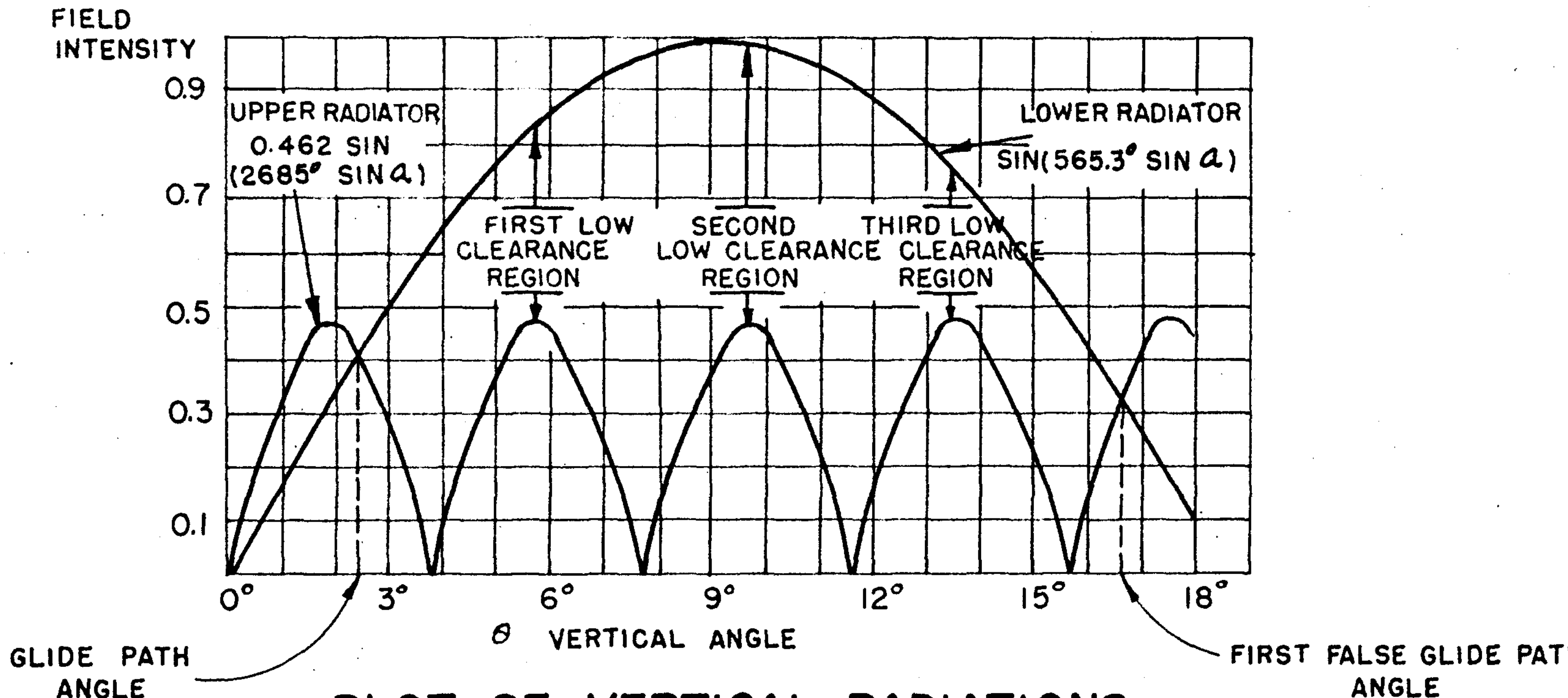


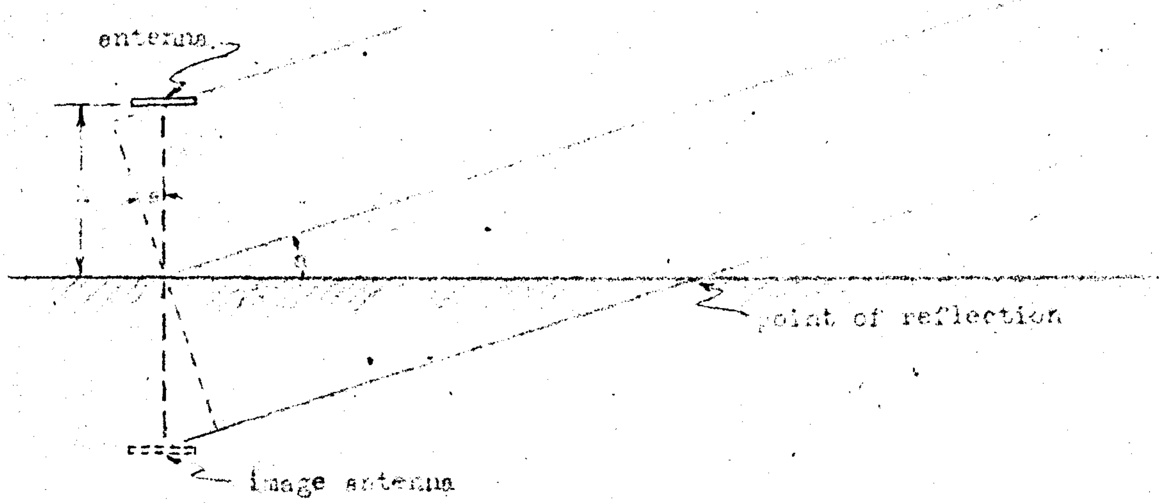
Formation of Glide Path
from Upper and Lower Antenna Signals

Figure 3



PLOT OF VERTICAL RADIATIONS FROM GLIDE PATH ANTENNAS

FIGURE 2



$$F' = R'(\theta)\,R'(a)\,\sin\left[\omega t - h \sin a\right] - R'(\theta)\,R'(a)\,\sin\left[\omega t - h \sin a\right] \qquad (1)$$

$$= -2R'(\theta)\,R'(a)\,\sin\left[h \sin a\right] \cos \omega t \qquad (2)$$

$$F = R(\theta)\,\sin\left[h \sin a\right] \qquad (3)$$

$R'(a)$ represents the vertical radiation characteristic of the antenna. It is nearly constant over a range of small angles near the ground.

$R'(\theta)$ represents horizontal radiation characteristic of the antenna.

Figure 5

THEORETICAL BASIS FOR GLIDE PATH

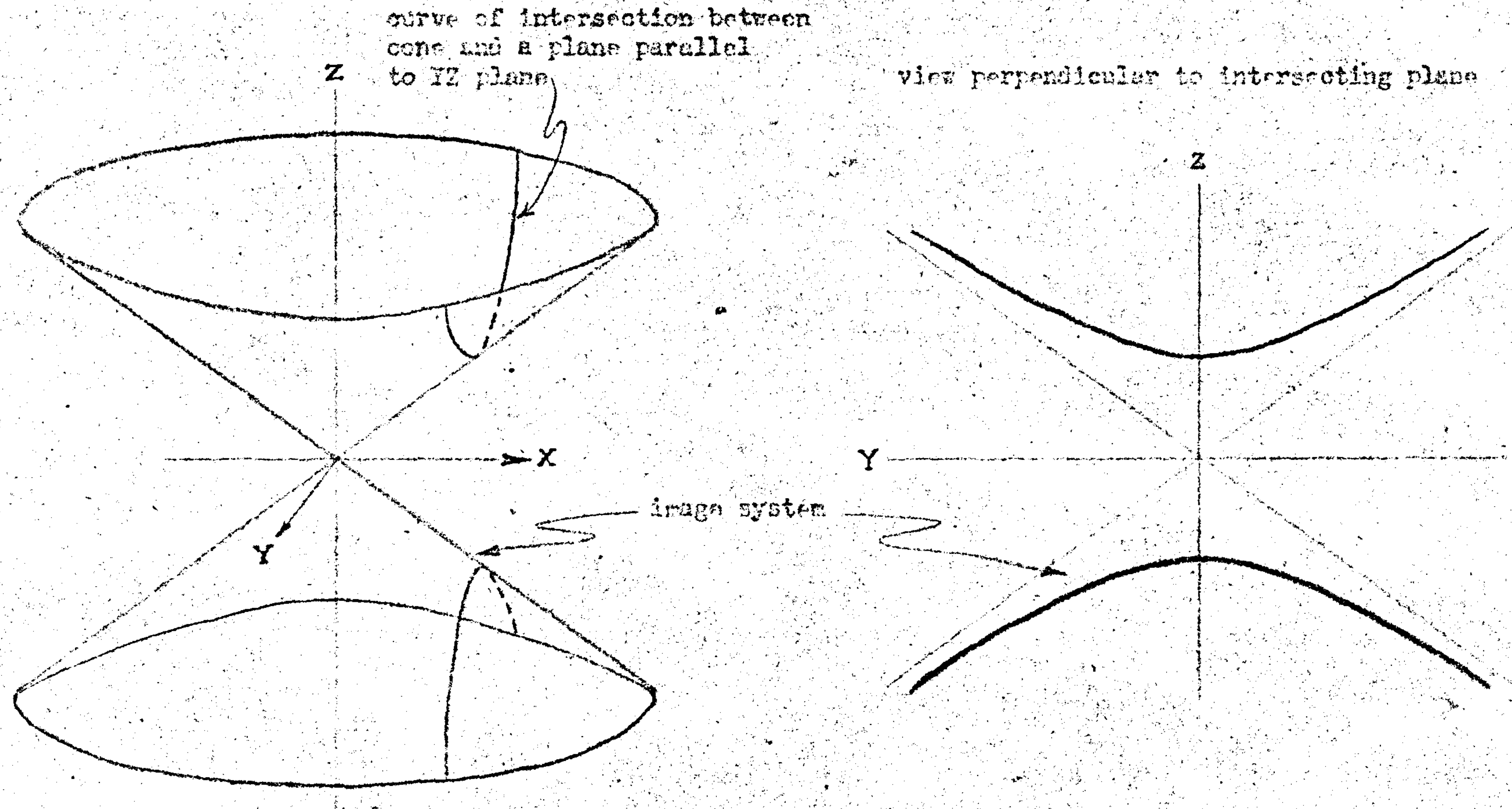
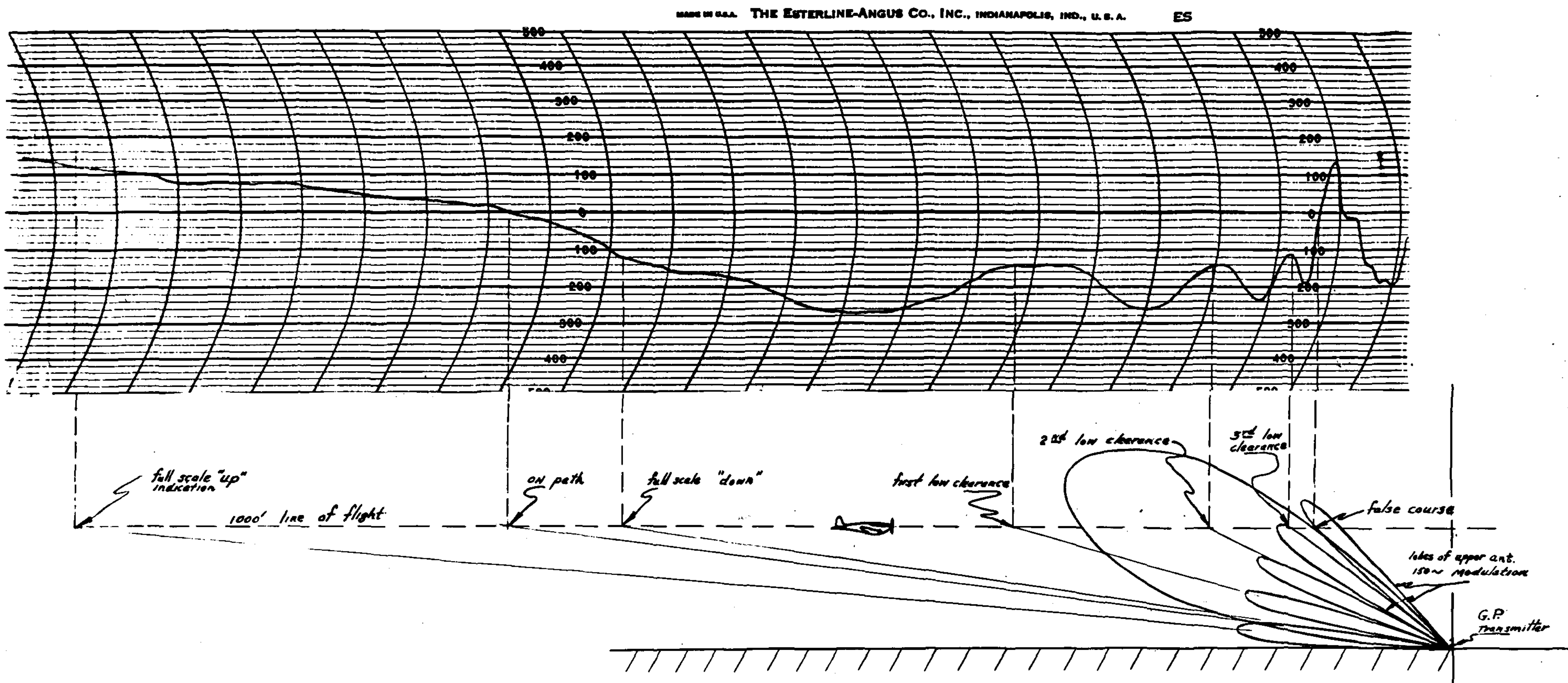
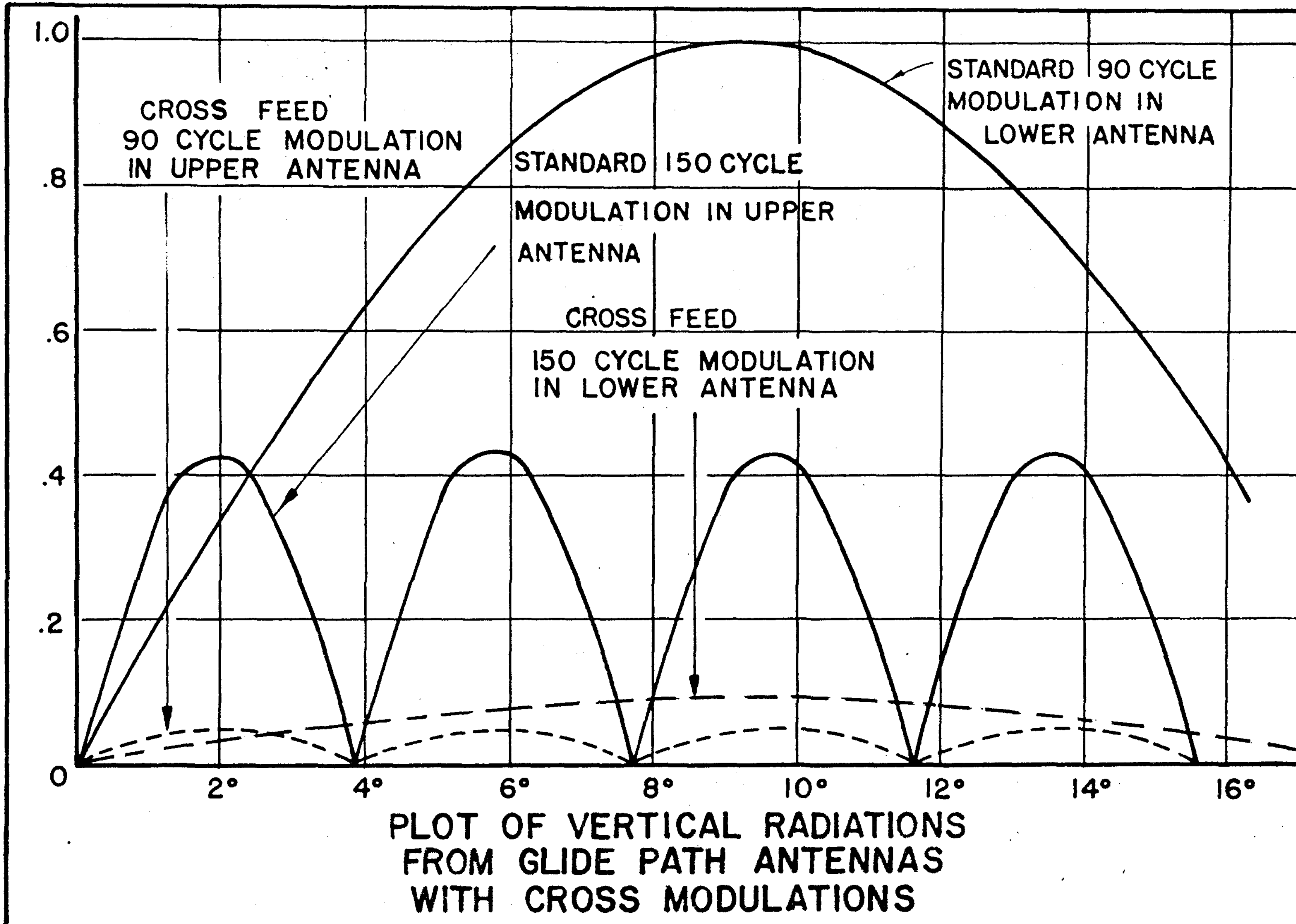


Figure 4

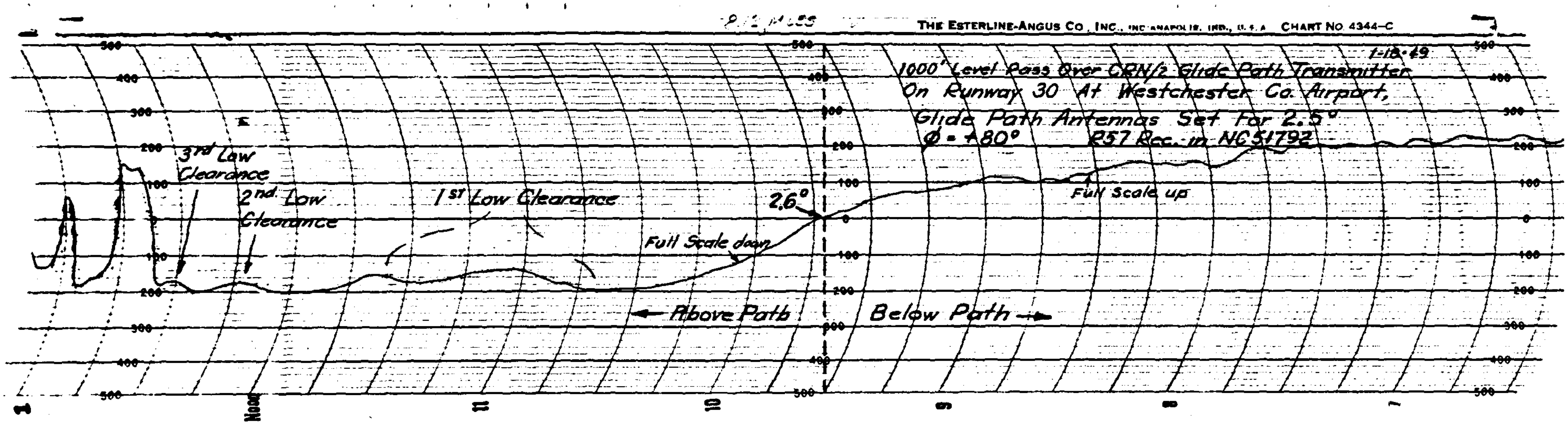


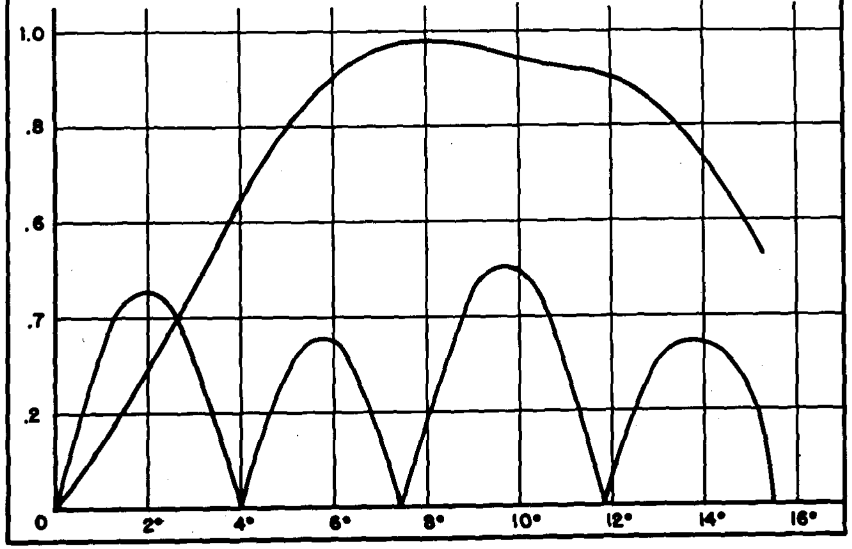
Method of Recording Signal Received in Constant Altitude Flight to analyze operating Conditions & adjustment of Glide Path Equipment.



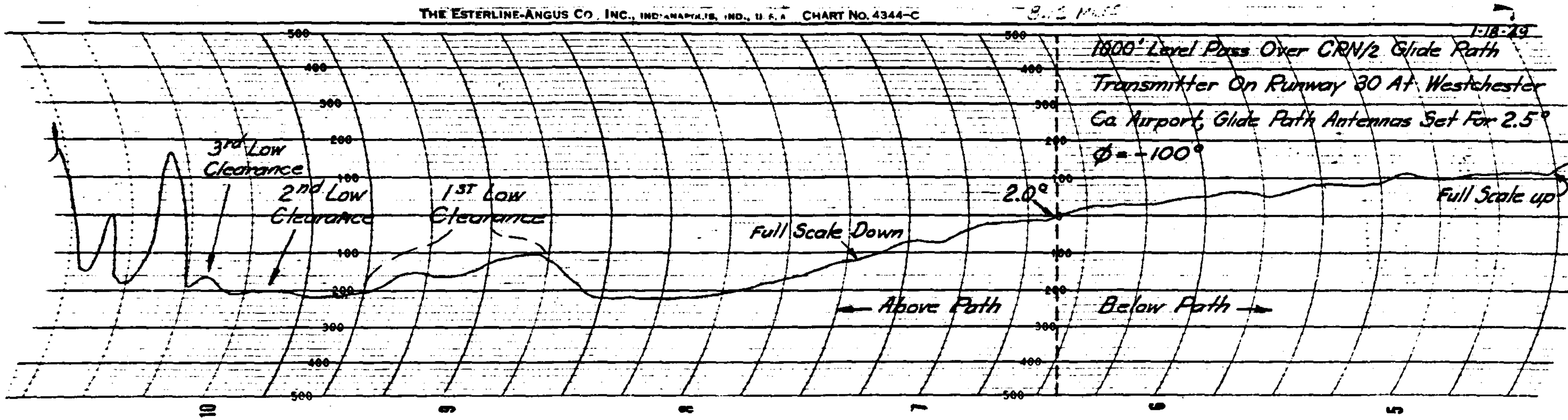
1.0
.8
.6
.4
.2
0
2°
4°
6°
8°
10°
12°
14°
16°
STANDARD 90 CYCLE MODULATION IN LOWER ANTENNA
CROSS FEED 90 CYCLE MODULATION IN UPPER ANTENNA
STANDARD 150 CYCLE MODULATION IN UPPER ANTENNA
CROSS FEED 150 CYCLE MODULATION IN LOWER ANTENNA
PLOT OF VERTICAL RADIATIONS FROM GLIDE PATH ANTENNAS WITH CROSS MODULATIONS

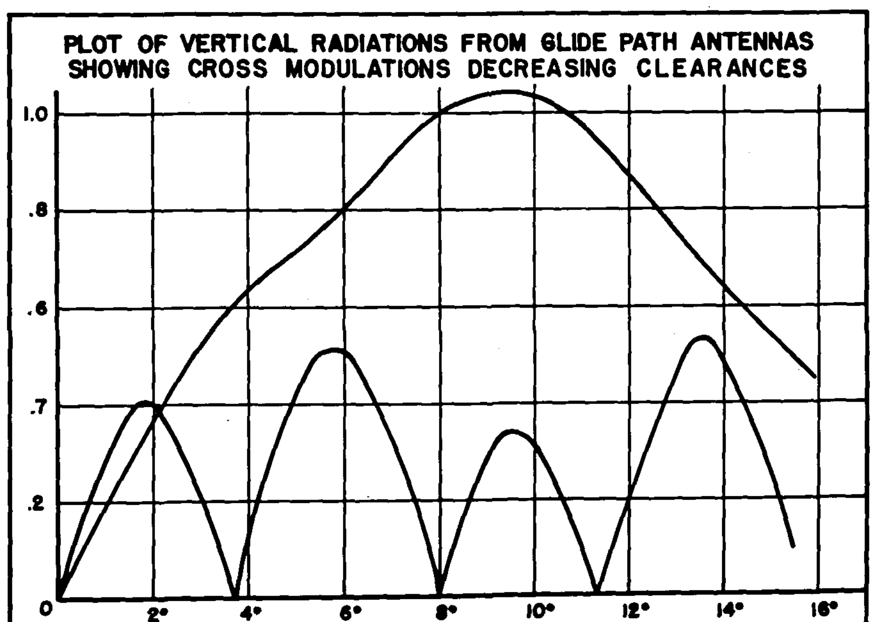
FIGURE 6



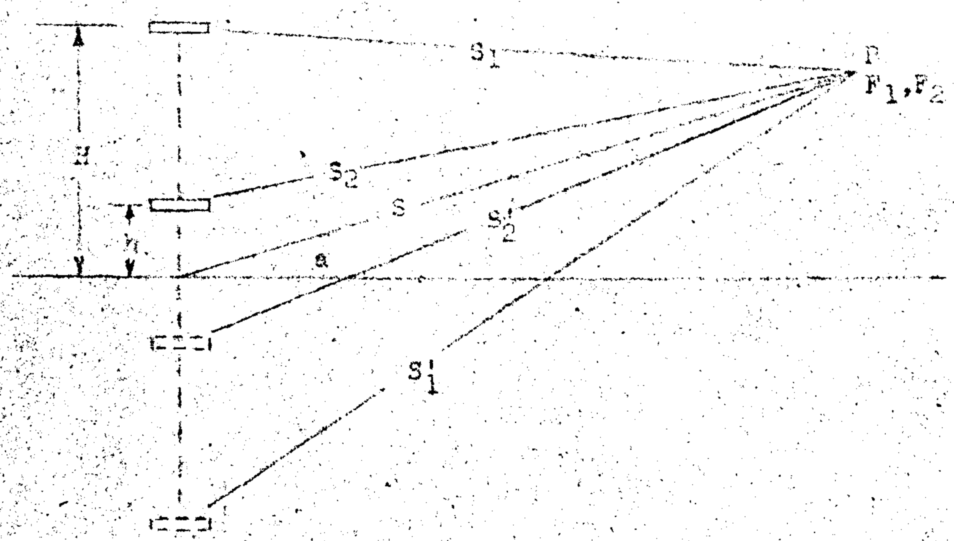


PLOT OF VERTICAL RADIATIONS FROM GLIDE PATH ANTENNAS SHOWING CROSS MODULATIONS INCREASING CLEARANCES





PLOT OF VERTICAL RADIATIONS FROM GLIDE PATH ANTENNAS SHOWING CROSS MODULATIONS DECREASING CLEARANCES



$F_1 =$ total signal of upper antenna and its image

$= 2 \sin(H \sin a) \cos\left(\omega t + S + \frac{H^2}{2S}\right)$

$F_2 =$ total signal of lower antenna and its image

$= 2 \sin(h \sin a) \cos\left(\omega t + S + \frac{h^2}{2S}\right)$

$\phi_1 =$ phase of the resultant radiation from the upper antenna and its image at point P with respect to the phase of the upper antenna.

$= S + \frac{H^2}{2S}$

$\phi_2 =$ phase of the resultant radiation from the lower antenna and its image at point P with respect to the phase of the lower antenna.

$= S + \frac{h^2}{2S}$

$\phi_T = \phi_1 - \phi_2 = \frac{H^2 - h^2}{2S}$

For a $2\frac{1}{2}°$ glide path $H = 2685°$ $h = 565.3°$

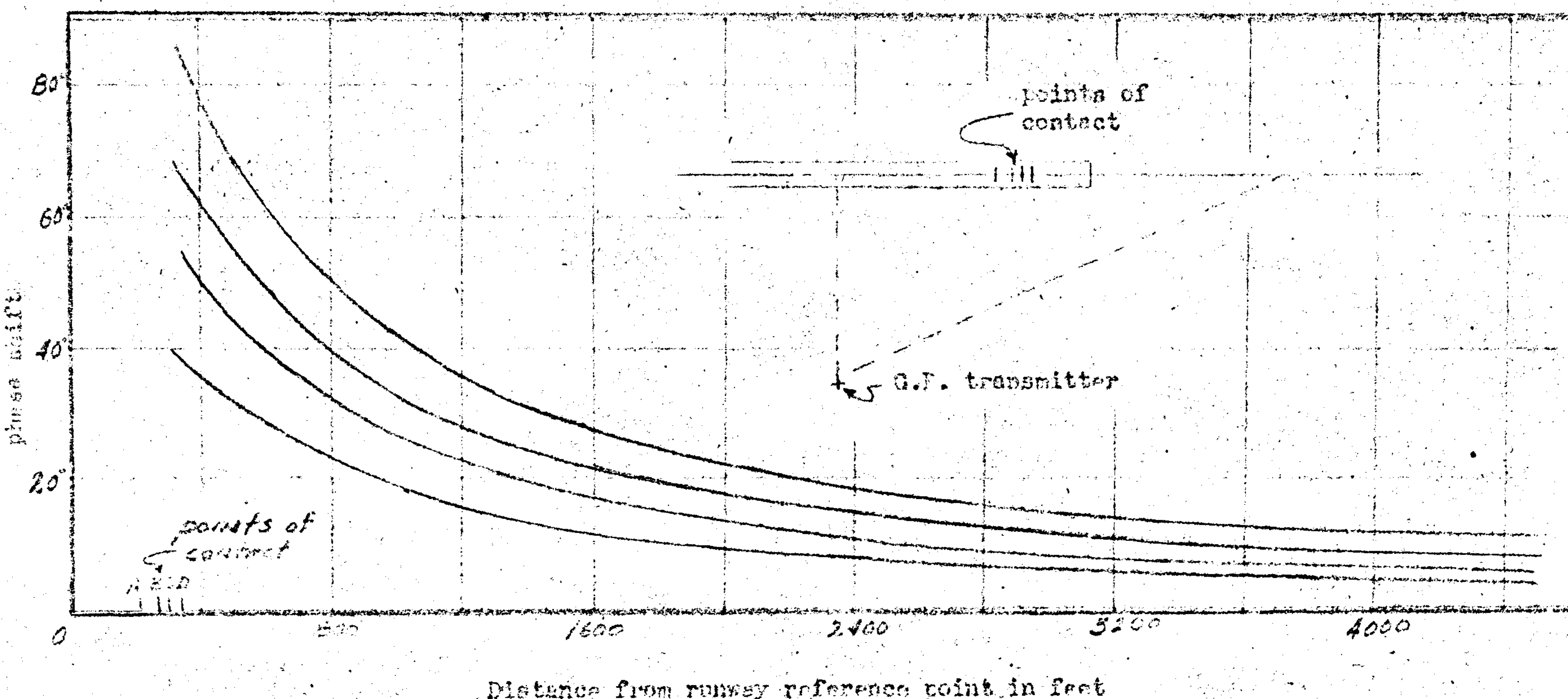
$\phi_T = 6.88° \times 10^6 / 2S$

At 400 feet from radiation equipment (at 335 mc 400 feet $= 48,960°$)

$\phi_T = \frac{6.88° \times 10^6}{2 \times 48960} = 70$ degrees

Phase Relations of Radiated Signals

Figure 9

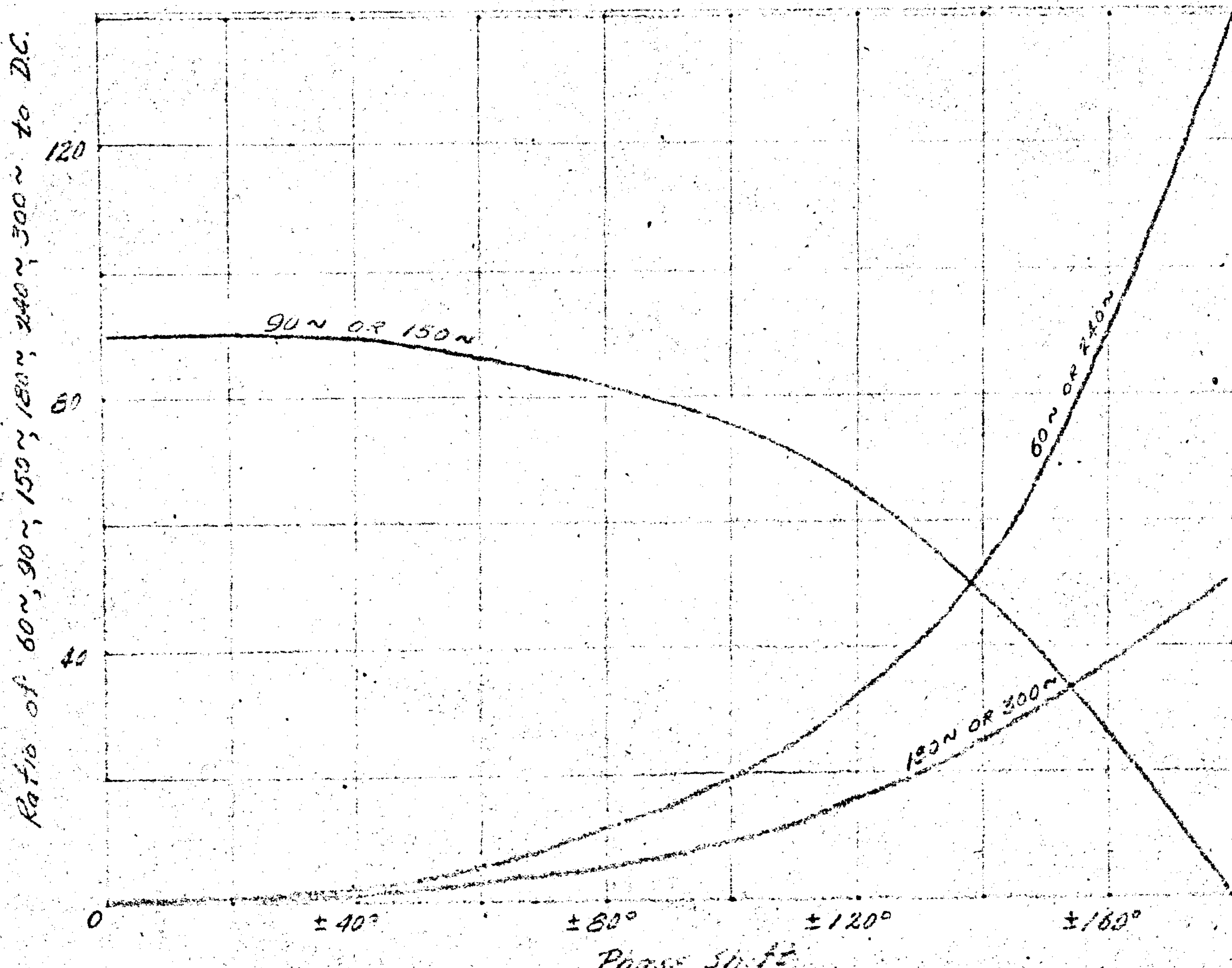


Transmitter located 400 feet from centerline of runway

Point of contact	A	B	C	D
Glide Path angle	3	2½	2¼	2

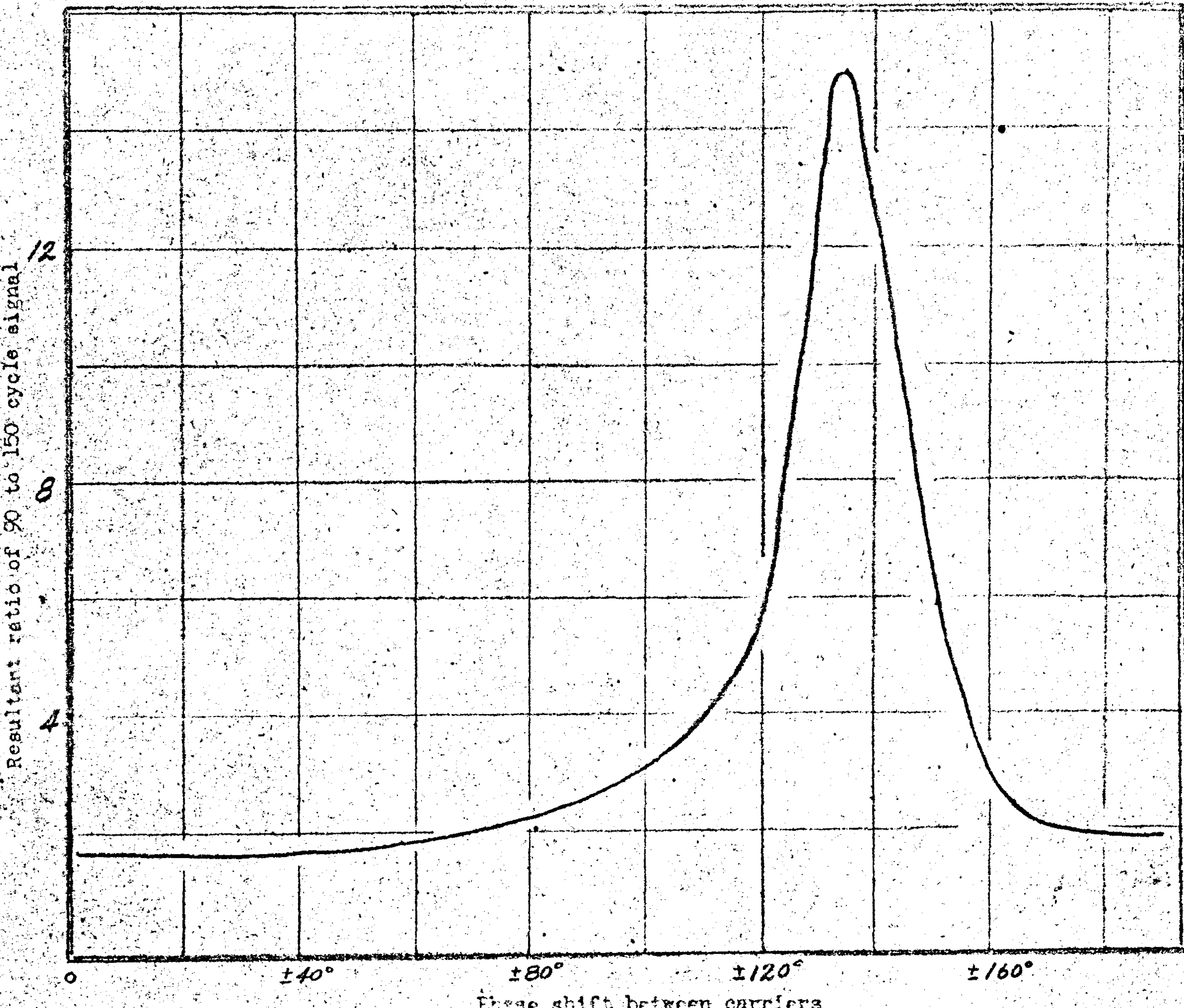
Phase Shift along Glide Path

Figure 10



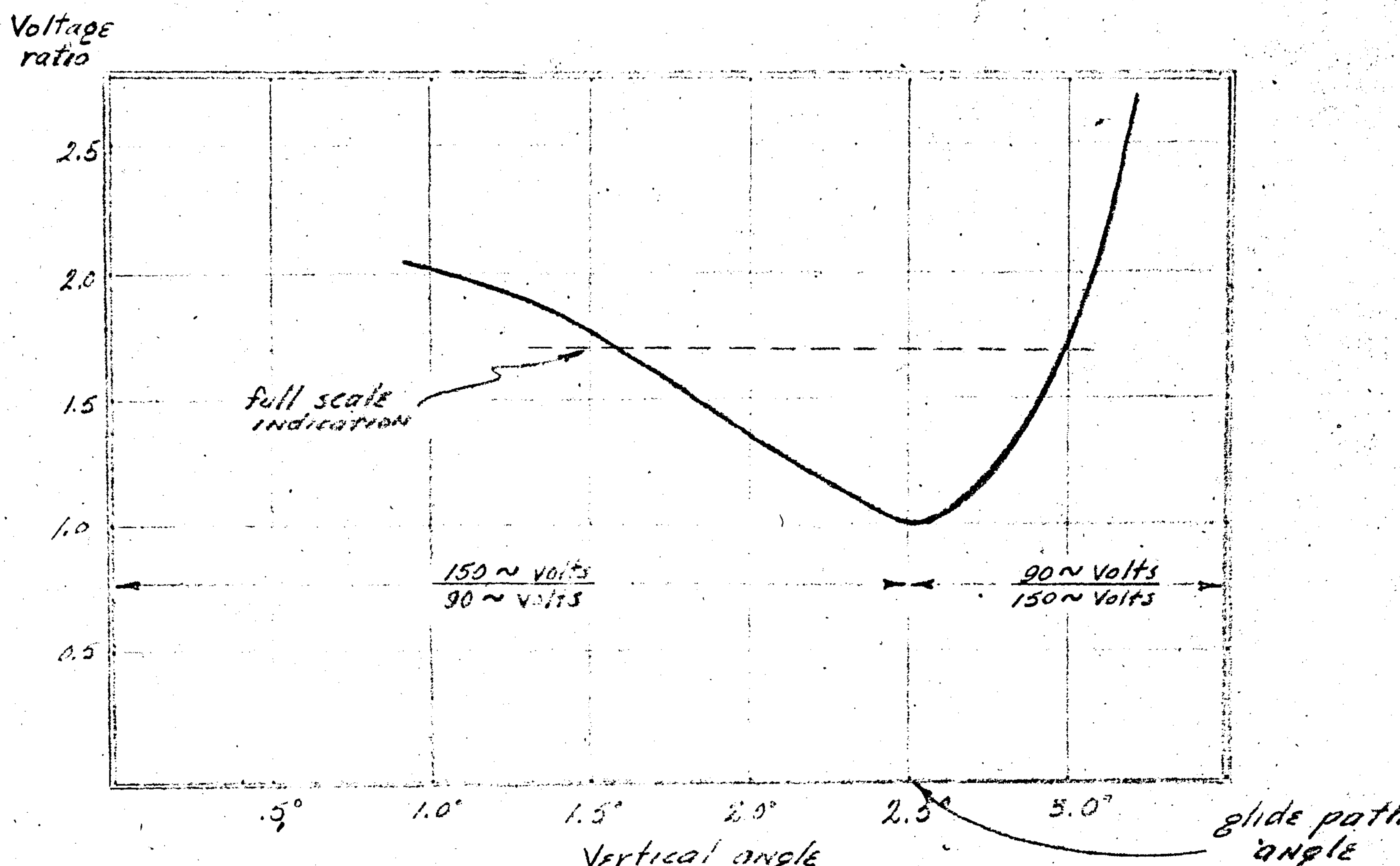
Distortion in Modulated Wave due to Phase Shift of Carrier
with respect to side bands

Figure 11



Effect of Phase Shift on ratio of Modulation Voltages

[illegible] 17



Relative sharpness of indications about the path determined from the ratio of modulation voltages

Figure 13